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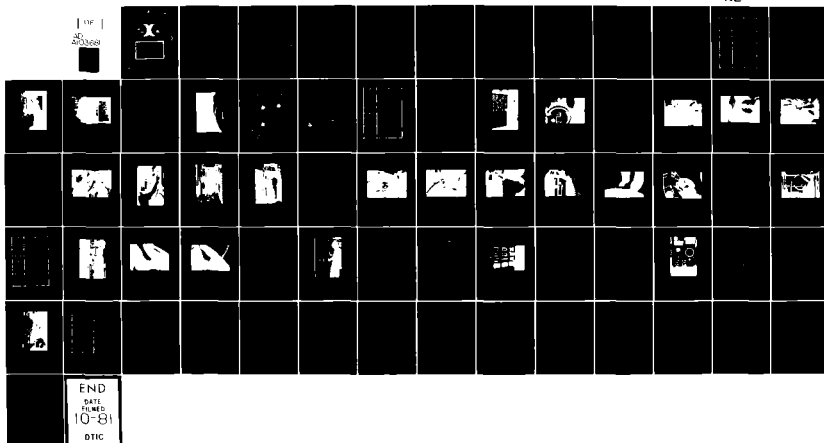
HUMAN ENGINEERING EVALUATION OF THE HYPERBARIC RESEARCH FACILITY--ETC(11)

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**HUMAN ENGINEERING EVALUATION  
OF THE  
HYPERBARIC RESEARCH FACILITY  
(PHASE 1)**

**J.I. Brady and M.D. Curley**

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dealt with control panel layouts, functional grouping, gauge placement, and chamber habitability. With respect to the environment, noise and light levels were carefully measured. At the present time, the most serious problem identified involves the excessive noise levels in the control area of the chambers. Octave band analysis reveals that: 1) the primary noise sources are the life support loops and the building air conditioning system, and 2) because of the frequency distribution of the noise, ear protectors are not a viable solution since the peak noise levels fall in the same frequency range as the peak levels in male speech. The noise levels must be reduced at the sources if speech communication among watch standers is to be unaffected. Light levels (luminance) throughout the complex generally fall within acceptable limits (1-20 ft-L). A review of personnel requirements has demonstrated the necessity for increased manpower if a fully functional deep saturation dive capability is to be maintained. Lastly, an analysis of the HRF's emergency system displays demonstrated their high attention-getting value through both auditory and visual alarms, and good readability. It was felt, however, that a consolidated annunciator alarm panel be incorporated into the central monitoring console which will be constructed eventually for the diving officer and supervisor. As the HRF becomes operational and HMPC personnel gain additional experience with it, further deficiencies may become evident.

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## INTRODUCTION

Construction of the Hyperbaric Research Facility (HRF) is now complete. Functional testing by the contractor and correction of problems identified during that testing is currently underway. When the facility is officially turned over to the Navy, it will be engaged in many aspects of hyperbaric research and will be an integral part of the Naval Medical Research Institute.

If a system of the size and complexity of the HRF is to be operated safely and efficiently, an adequate man-machine interface must exist. In other words, human engineering design criteria should have been incorporated in the HRF during its preliminary design stages. Unfortunately, this procedure was not followed in the case of the HRF. In fact, there has never been a formal human engineering program included as an integral part of the design and construction phases of any existing Navy hyperbaric chamber complex. Historically, major retrofit programs have been required on every major Navy hyperbaric chamber complex. These programs have been initiated after completion of construction to remedy design deficiencies which became apparent either during construction or during operational testing.

Although it was too late to have an impact on the initial design of the HRF, a thorough evaluation of the system was required for two reasons: (a) to identify existing human engineering deficiencies and make recommendations for their short-term correction, and (b) to provide information regarding the optimum configuration for the system in future retrofit planning. Of primary concern in this evaluation was the chamber complex (i.e. habitability

and safety), its associated control consoles, and the various watch stations. The importance of chamber habitability on the subsequent performance and psychological well-being of divers during long demanding saturation dives has become increasingly evident. The control consoles and watch stations present the greater concentration of information for the chamber operators, and as such, present the greatest potential for operator error.

A review of the literature reveals that while human engineers are beginning to make an impact in the design of various diving systems (1, 2, 3) their attempts have been generally limited in scope and were conducted frequently after the initial design was already completed. There has been, however, considerable research accomplished in the areas of information processing, control/display relationships, workspace design, etc. which are of significant importance in the present evaluation (4, 5, 6, 7, 8).

A preliminary human engineering evaluation of HRF mockup control consoles has already been conducted (9), and recommendations were made regarding specific changes. The actual consoles are presently in place and a complete evaluation was feasible. Since the HRF has been completed, an overall system evaluation was possible. This evaluation has reviewed the findings of the preliminary study of the control consoles and has addressed other facets of the HRF such as operator watch stations, HRF subsystems, personnel requirements, environmental parameters, and chamber habitability.

#### MATERIALS AND METHODS

Due to the complexity of the HRF, the evaluation was accomplished systematically by dividing the analysis into five general areas. It was recognized from the outset that these areas would not be mutually exclusive and that a high degree of overlap would exist. These areas were: 1) operator watch stations, 2) HRF subsystems, 3) environmental parameters, 4) personnel

requirements, and 5) emergency systems/alarms. It was hoped that through this relatively arbitrary division no aspects of the system would go unnoticed.

The Phase I evaluation sought to identify existing human engineering deficiencies: 1) by a comparison with accepted human engineering guidelines, as stated in MIL-STD-1472B, as well as additional human factors source references such as Van Cott and Kinkade (4), and 2) through extensive interviews with contractor and U.S. Navy personnel who were integrally involved in the HRF's construction and functional testing. These interviews usually involved on-site step-by-step reviews of the function and layout of control panels, subsystems, information displays, etc. The result is a compilation of observed deficiencies and recommendations, and suggested additions or modifications.

#### RESULTS

The following compilation of findings is grouped by the previously mentioned divisions or areas in which the overall analysis was conducted. In addition, each finding is assigned a priority number from one to four. In order for an observed deficiency to be classified as a very high "Priority 1," it had to involve, in the opinions of the authors, a critical potential safety hazard or pose a condition which greatly limited the practical readiness of the system for operational use.

Operator Watch Stations and HRF Subsystems: For purposes of convenience and because of the significant overlap, these two areas have been grouped together:

- (1) To aid in location description and because it is consistent with the Navy's other shore-based deep diving saturation complex, the chambers should be identified by the letters A-E as indicated in Fig. 1. As will be seen in the upcoming recommendations for

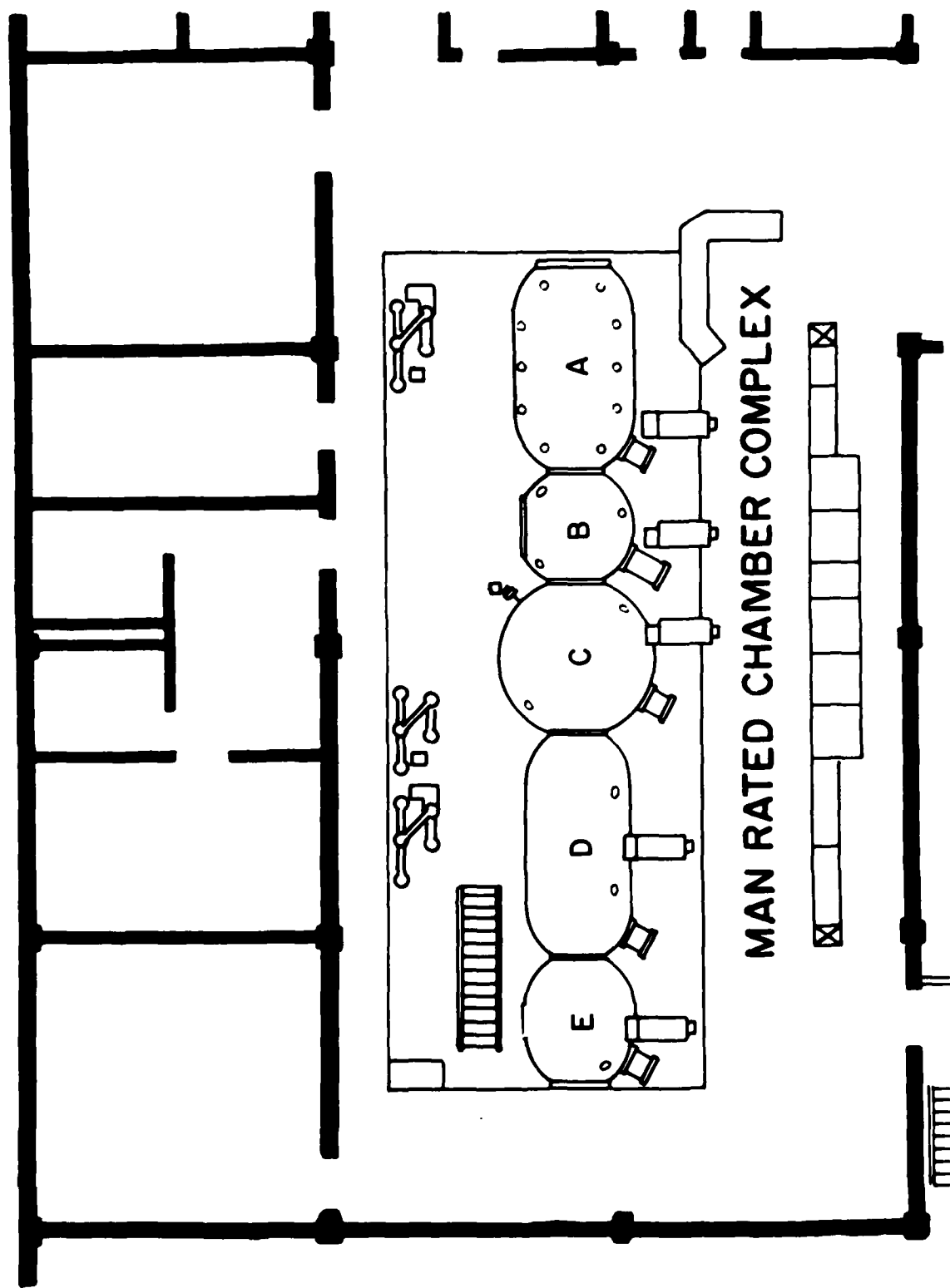


Fig. 1. The five chambers comprising the HRF saturation chamber complex.

control panel changes, this system lends itself readily to functional grouping techniques and color-coding. (Priority 2)

- (2) Due to the present control panel design, operation of the appropriate valving and control devices requires the operator to stand. A panel design which would provide for efficient operation by a sitting operator, while highly desirable during long saturation dives, would require extensive modification of the existing panels and would involve substantial cost and time considerations. A complete redesign of the control panels should be undertaken during the first major retrofit. (Priority 4)
- (3) Since control panel operators will be required to stand while actually manipulating the controls, but will probably sit at their watch stations most of the time during saturation dives, it is recommended that comfortable low-level swivel chairs with arm rests and lumbar support be provided for their use. (Priority 2)
- (4) Even when standing, certain operators will have difficulties reaching all necessary control devices (Fig. 2). Consequently, it is recommended that a 4-in. high padded deck be added to the existing concrete surface directly in front of the master control consoles. This deck should not extend out to the local control panels or the gas analysis panel; however, these areas should be provided with a durable padded surface of no more than 1-in. in height. (Priority 2)
- (5) After much consideration, it is felt that completely enclosing the control area for purposes of sound attenuation is impractical due to the extent of overhead piping (Fig. 3). The major sound sources should be attenuated if possible at their sources (i.e., ACS blowers and building air conditioning). A solution involving the wearing of



Fig. 2. Diver of fifth percentile height having difficulty reaching chamber closure button.

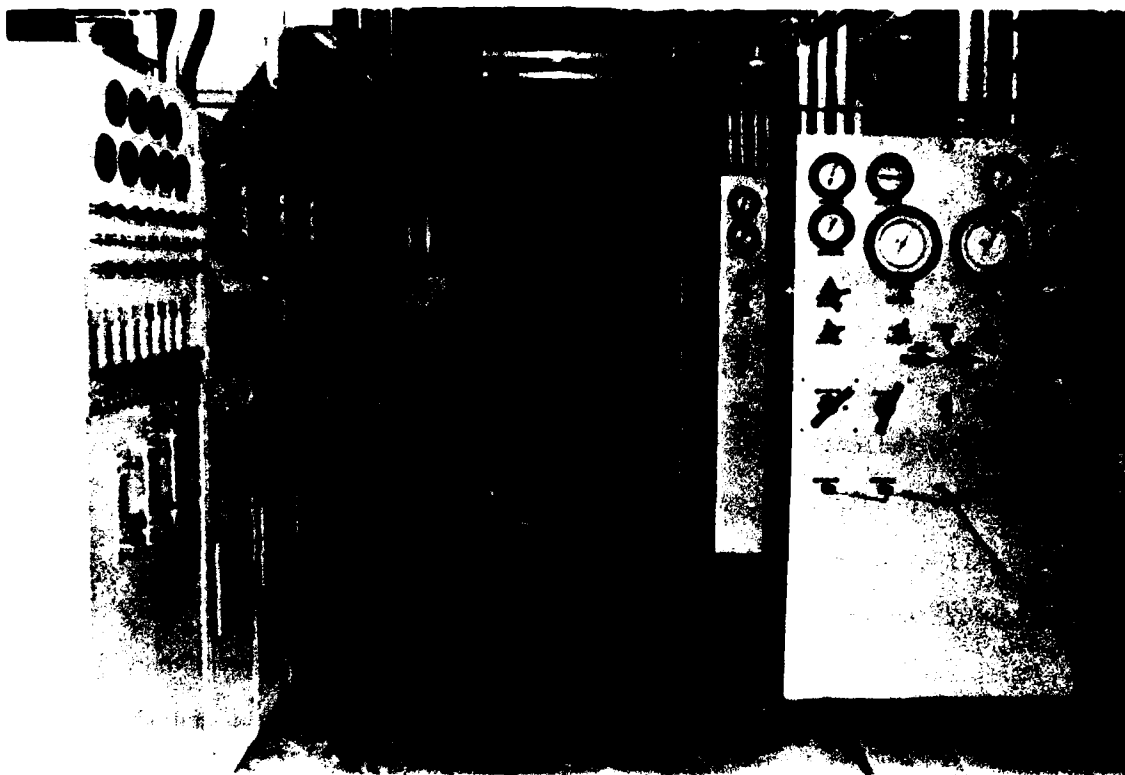


Fig. 3. Operating and local panels in master control area. Note extent of overhead piping.

ear protectors by personnel should be avoided if at all possible.

(Priority 1)

- (6) Currently a gap exists between the metal deck in the control area and the side of the chamber (Fig. 4). Since tools or objects could accidentally be dropped into the pit below injuring someone or damaging equipment, it is recommended that this gap be closed off in some manner.

(Priority 2)

- (7) The present console design does not provide an adequate diving officer and diving supervisor watch station. Such a watch station should function primarily as a central monitoring location. Figures 5 and 6 show a recommended layout for this watch station. Figure 7 indicates the suggested location for the station. This location provides a complete view of the master control consoles, as well as easy access to the medical research area and visitor observation areas.

(Priority 2)

- (8) It is recommended that all outside telephones in the immediate chamber area be located at the central monitoring console and that no more than three outside lines be installed.

(Priority 3)

- (9) In the present communications system, the intercom and headphone loops can not be operated simultaneously through helium speech unscramblers (HSU), since the present design incorporates only one HSU. It is recommended that a second HSU be added to the system.

(Priority 2)

- (10) It would be desirable to have all communication mixers and amplifiers in one location for more efficient access and adjustment.

(Priority 4)





Fig. 4. Diver indicating 3-4 in. gap between deck and chamber.

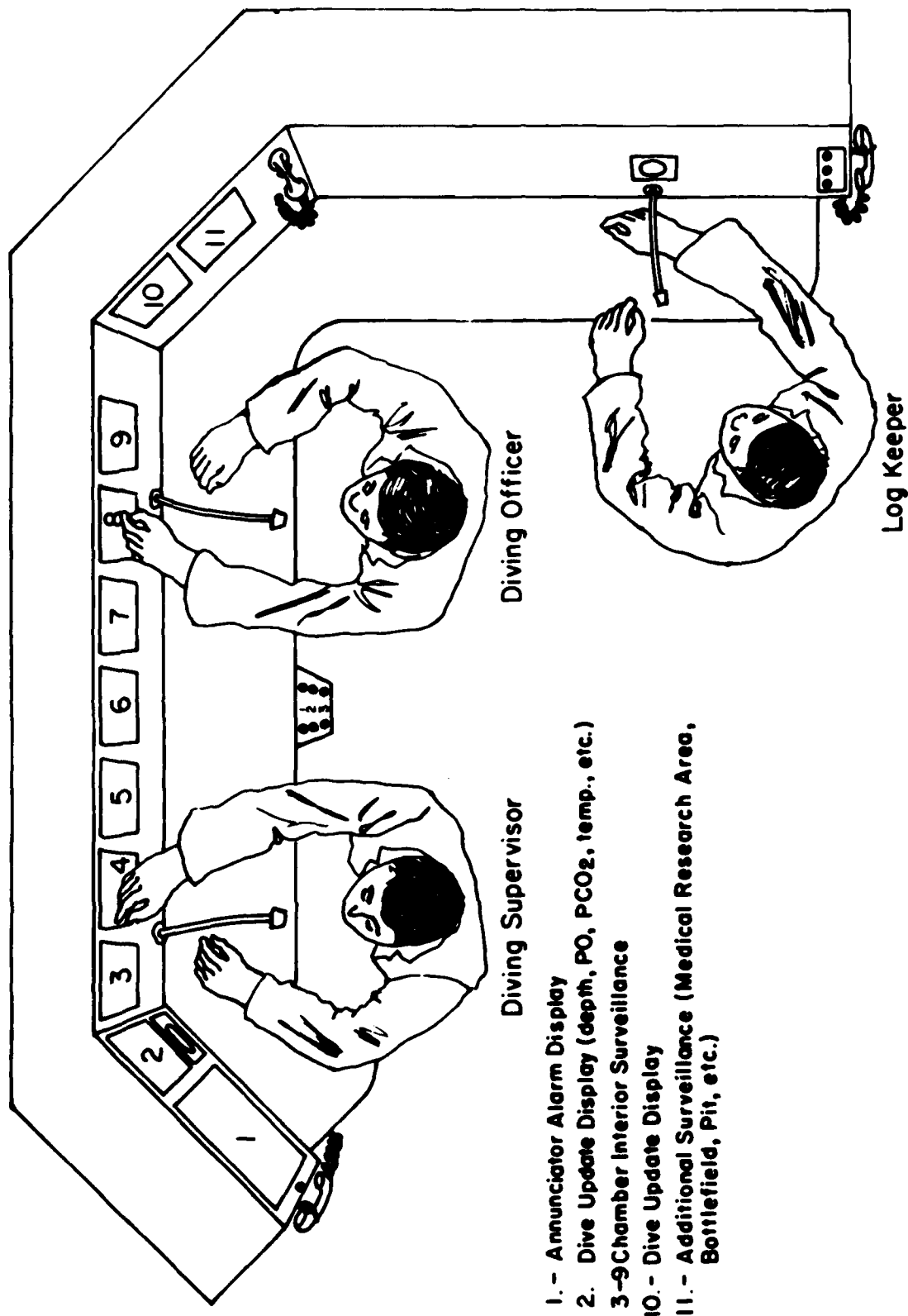


Fig. 5. Possible layout for a central monitoring console to accommodate the diving officer, diving supervisor, and log keeper.

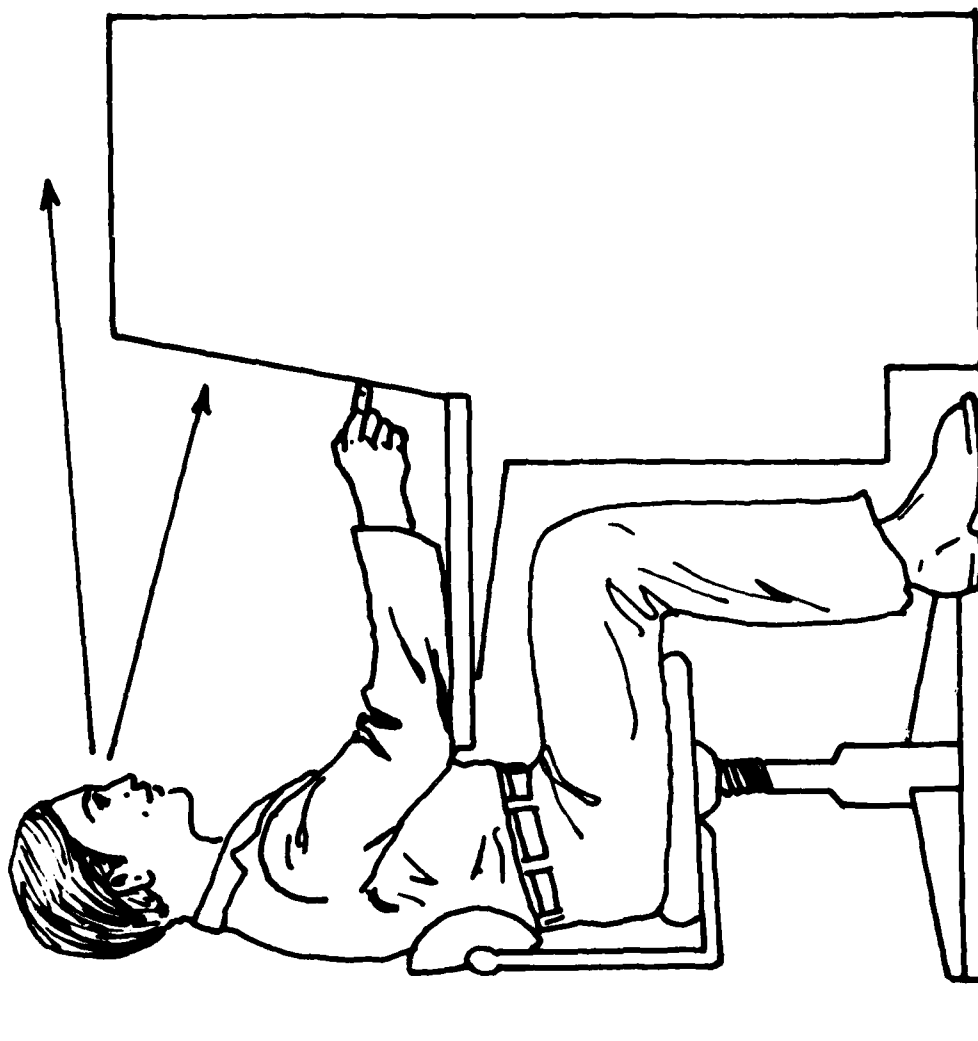


Fig. 6. Side view of a central monitoring console for a seated operator.

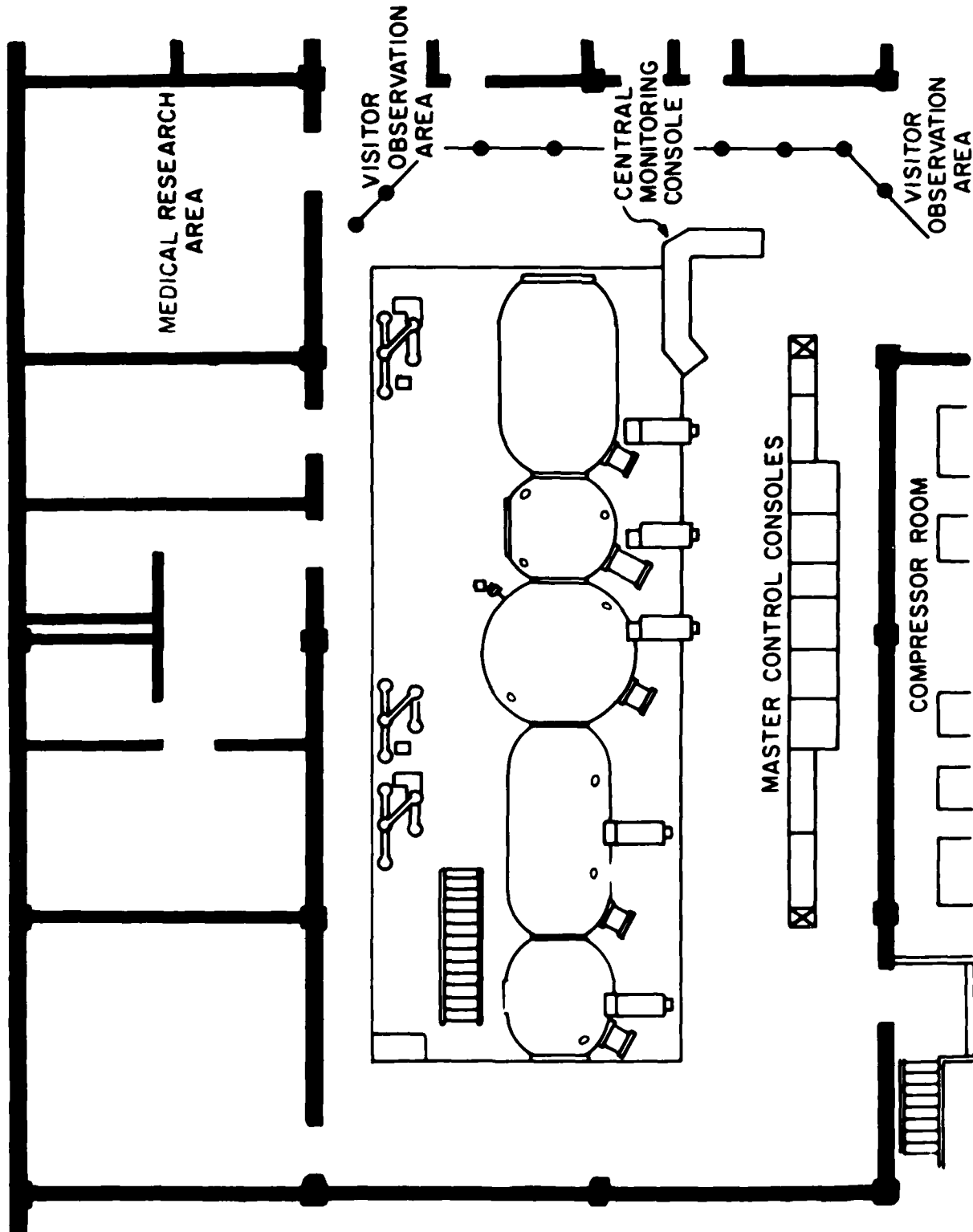


Fig. 7. Recommended location of central monitoring console.

- (11) Intercom and headphone communication loops should have outlets in the medical research area. (Priority 2)
- (12) The pit should be equipped with at least one communication station containing intercom and headphone loops. Two stable self-standing rollaway ladders should also be provided for each side of the pit to minimize potential safety problems when operators are required to reach overhead valves. (Priority 3)
- (13) Compressor room and bottlefield should each have at least one intercom station. A station could be located in the Gas King's office in the compressor room, and a station could be installed on the truck charging end of the covered bottlefield alleyway. To aid the training of new personnel and to reduce the possibility of human error, it is suggested that painted floor labels be provided for each compressor in the compressor room. (Priority 3)
- (14) A selectable TV monitoring capability should exist within the medical research area immediately adjacent to the chambers. This capability will allow researchers to monitor and direct the progress of divers within the chamber on their various experimental procedures. (Priority 2)
- (15) A selectable TV monitor capability should exist in the Office of the Director of Hyperbaric Medicine Program Center. (Priority 4)
- (16) The sound-powered phone cord on the local panels (Fig. 8) should exit on the chamber side of the panel to prevent cord interference with valve operation on the panel front. (Priority 3)
- (17) The present design of the external medical lock hatch causes inefficient and time-consuming delays in its opening and closing (Fig. 9). Alternative design configurations should be investigated. (Priority 1)

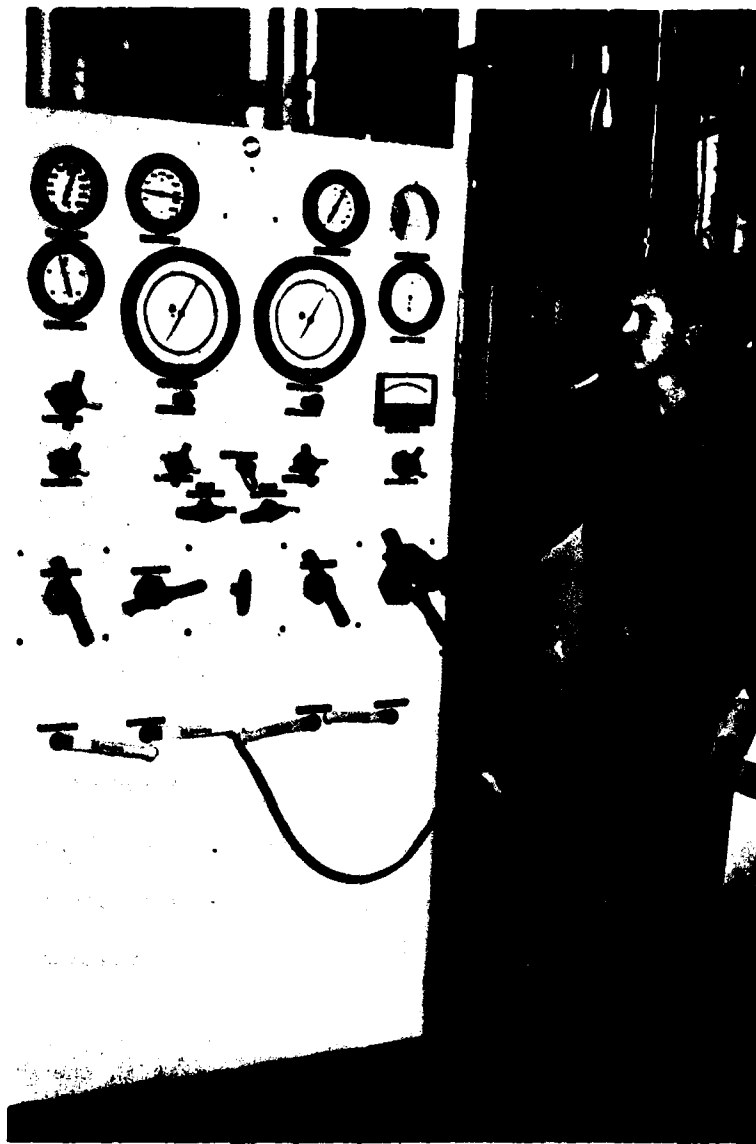


Fig. 8. Local panel with sound-powered phone cord amidst panel valving.

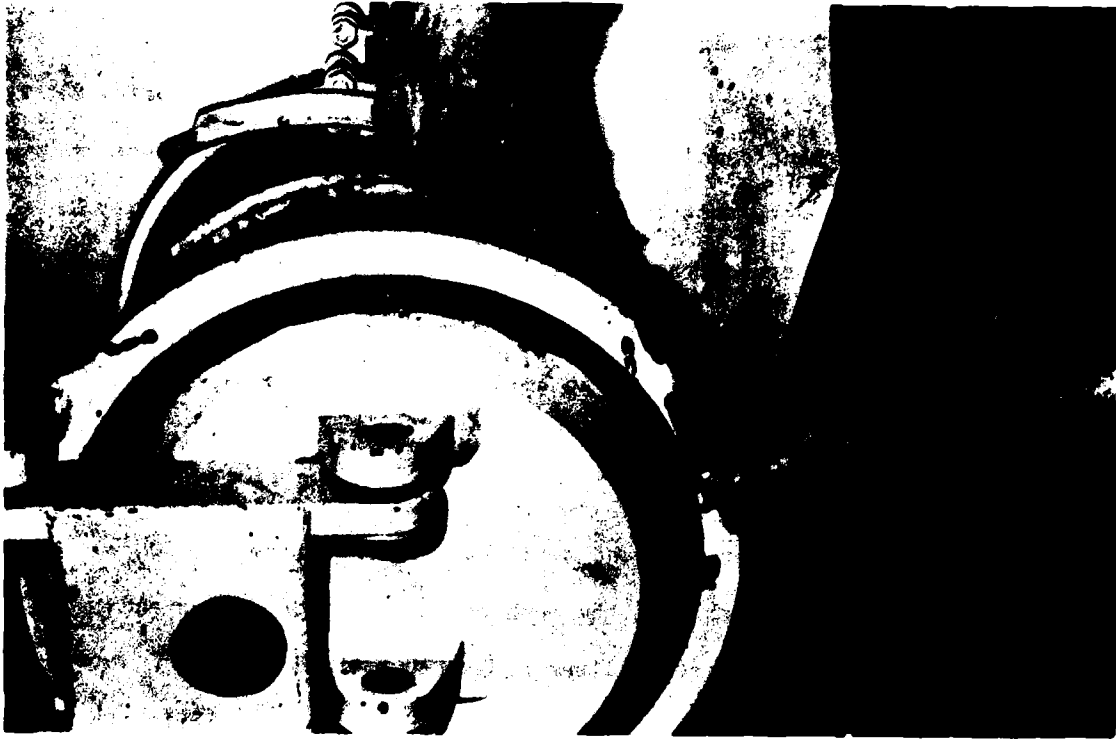


Fig. 9. Present design of external medical lock hatch.

- (18) With respect to the atmosphere conditioning system, the most prominent interface problem observed was the inefficient and time-consuming design of the cannister access hatch (Fig. 10). The lid valve, plastic "preventer," and retaining ring pose substantial time delays when a cannister change is required. It is recommended that alternative designs be evaluated for a future modification. (Priority 2)
- (19) All CO<sub>2</sub> absorbant cannisters should be interchangeable from one housing or loop to another. (Priority 2)
- (20) It has been observed that spokes may be necessary to hold the small mesh central tube in the cannisters from being moved slightly out of position when the large tube is filled with CO<sub>2</sub> absorbant (Fig. 11). When the small central tube is out of position, threading of the cannister cap is difficult. (Priority 3)
- (21) The possibility that dust and small particulates from the CO<sub>2</sub> absorbant may slip through the mesh of the cannister tubes and cause eventual downstream filtering problems should be investigated. (Priority 2)
- (22) In its present configuration, the fire extinguishing system (FES) holding tank drains directly on to the floor of the pit (Fig. 12). This will produce continuous maintenance problems as well as creating poor footing for personnel required to work in the area. It is recommended that drain pipes be added to carry the flow directly to the floor drains in the pit. (Priority 2)
- (23) When the FES is activated, spray coverage within the chambers, while adequate on the surface, is less than adequate when the chambers have been pressurized. Adjustment of the internal nozzles and



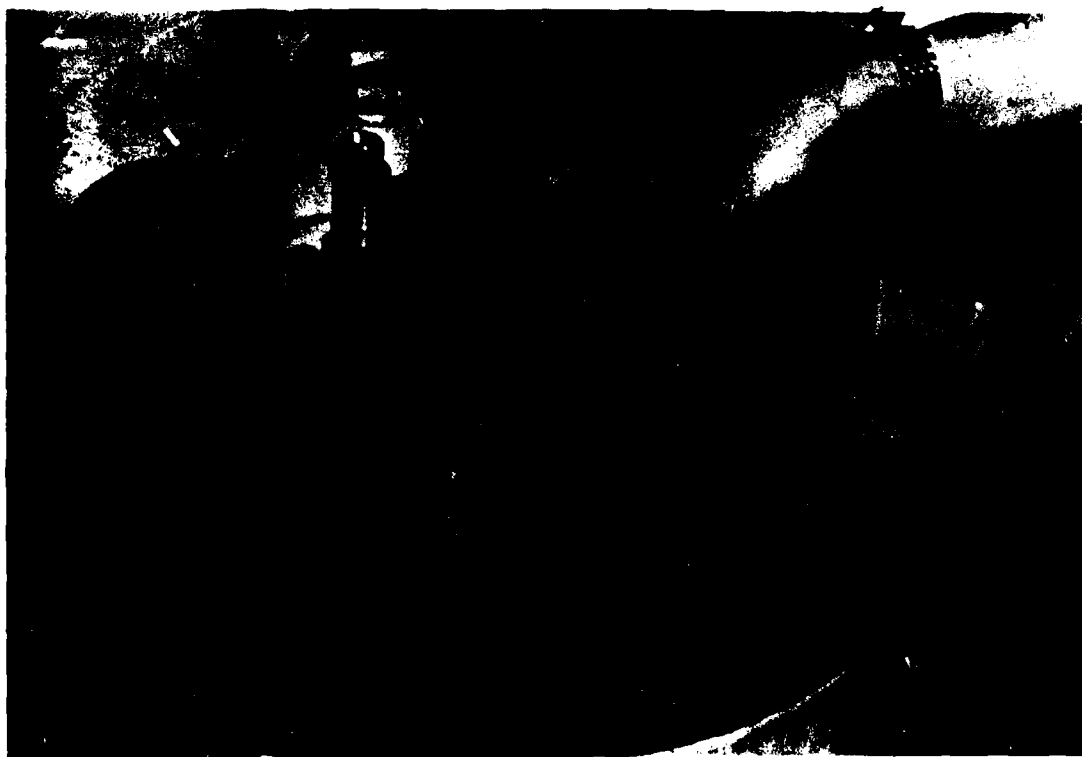


Fig. 10. Current configuraiton of canister access hatch.



Fig. 11. Diver indicating the small mesh central tube of a CO<sub>2</sub> cannister which may require spoked support when filled with CO<sub>2</sub> absorbant.



Fig. 12. Fire extinguishing system holding tank drain valve, which when open drains the tank onto the floor of the pit.

- modification of the FES pressure tracking system may be necessary if the problem is to be corrected. (Priority 1)
- (24) The design of the present FES lanyard pull inside the chamber may result in frequent inadvertent activations (Fig. 13). A lever or pushbutton design can still be operated quickly and yet would not lend itself to inadvertent operation. (Priority 2)
- (25) When the gas bottles are at normal storage pressures, the CPV valve handles in the bottlefield are difficult, if not impossible, to turn without using a special wrench. A different valve handle design is required or at least a special modified wrench should be obtained. (Priority 2)
- (26) Bank pressure gauges in the bottlefield should be repositioned or at least tilted down for more efficient viewing (Fig. 14). (Priority 4)
- (27) A slightly elevated walkway (1-2 in.) through the bottlefield alleyway will provide better footing, easier access to some difficult to reach valves, and greater readability of the bank gauges (Fig. 15). However, it should not be so high as to cause head clearance problems with lights, etc. (Priority 4)
- (28) A protective roof or hood to shield the bottlefield oxygen regulators and their associated valves from ice and snow in the winter is recommended (Fig. 16). (Priority 2)
- (29) Noise levels in the compressor room approach the recommended upper limits as established by OSHA for an 8 h exposure. A sound-attenuated office for compressor room personnel and ear protectors may be the only realistic solutions. (Priority 1)



Fig. 13. Fire extinguishing system lanyard pull in D chamber. A pull on the cord activates the system causing a water spray to drench the chamber contents.



Fig. 14. Fifth percentile diver having difficulty reading bottlefield bank pressure gauge.



Fig. 15. A solid, slightly elevated walkway is recommended for the bottlefield alleyway.

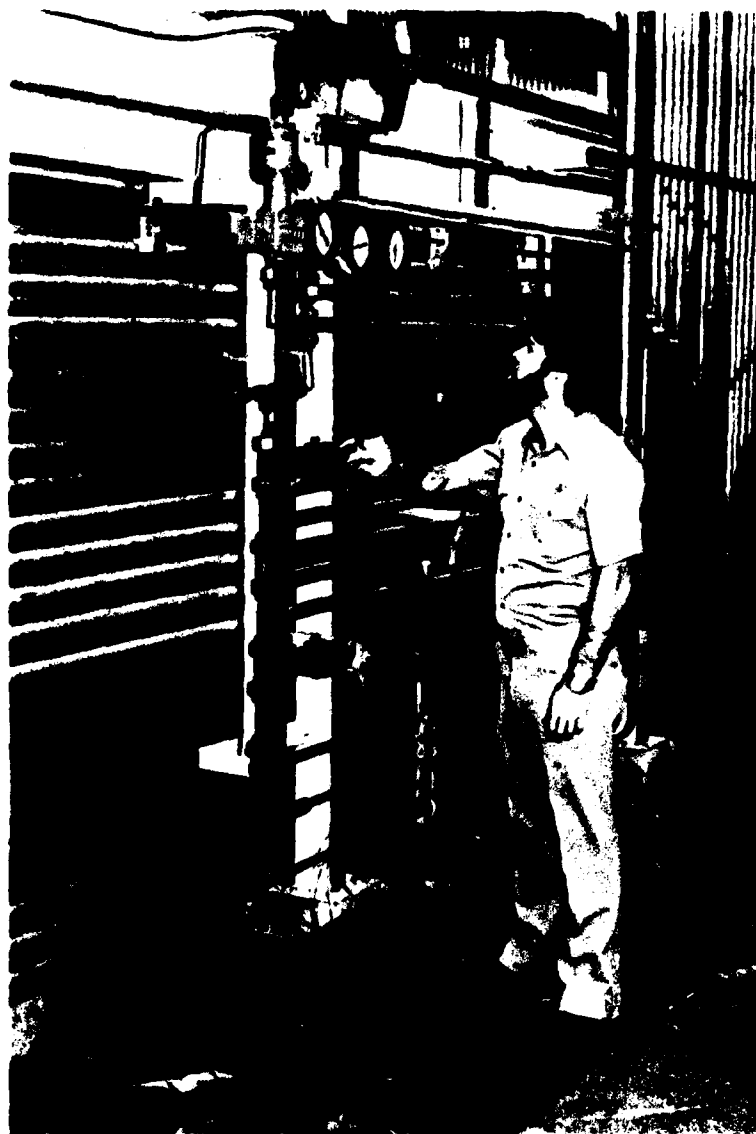


Fig. 16. Bottlefield oxygen regulators and valving are located outside and have no protection from inclement weather.



(30 - 51 refer to the chamber interior)

- (30) The overhead-mounted exhaust screens and FES outlets in D chamber will pose head clearance difficulties for divers taller than 71 in. (Fig. 17 and 18). Form-fitted vinyl or rubber pads on these components should reduce any minor injury that might occur during lengthy dives. (Priority 3)
- (31) The hinge of the medical lock hatch in D chamber impacts the BIBS connectors when swung open (Fig. 19). These connectors must be moved or a stop device for the hinge will be necessary to prevent eventual damage. (Priority 1)
- (32) Handles for the medical lock hatches are highly desirable, if divers are to use them frequently without injuring their hands and fingers. (Priority 3)
- (33) If the entire chamber complex is taken to depth (during a saturation dive for example), the open hatch door between E chamber and D chamber will prevent access to the sink (Fig. 20). Unless the sink is relocated or unless E chamber is left unpressurized, divers will have to partially close the rather cumbersome hatch each time they wish to use the sink. (Priority 2)
- (34) The present sink location may also result in possible splatter problems affecting the lower bunk. (Priority 3)
- (35) The lip of the deck plate retainer (Fig. 21) should be lowered to reduce possible foot and toe contact injuries. (Priority 4)
- (36) In addition, a smooth transition is required between the deck plates and chamber sides, particularly near the hatchways. (Priority 4)
- (37) Alternative toilet designs should be examined. Depending on the amount and direction of water flow, feces removal in current toilet design may be inadequate (Fig. 22). (Priority 3)



Fig. 17. Fire extinguishing system spray nozzles pose possible head impact problems for divers.



Fig. 18. Screened overhead penetrators pose head injury possibilities for divers over 71 in.



Fig. 19. Hinge of medical lock hatch contacting the BISS connectors in D chamber.



Fig. 20. Hatch opened in D chamber and obscuring the fold-down sink.



Fig. 21. Lip of deck plate retainer and gap next to chamber end wall.



Fig. 22. Present toilet bowl design.

- (38) The removable bunks in C chamber (Fig. 23) should be moved to permanent locations in other chambers. See Fig. 24 for recommended locations. (Priority 2)
- (39) Because the only access to the wetpot is through the chambers above, vertical and horizontal exercise bikes should be designed to fit through the necessary hatches. (Priority 3)
- (40) The current sanitary holding tank is not of adequate volume for frequent showers and toilet flushing (Fig. 25). It is recommended that a larger tank (75 gal) be installed. (Priority 1)
- (41) Presently the chamber complex has only one toilet and one shower. For a six man dive team and with the entire chamber complex at depth, a second toilet and preferably a second shower is required. This is particularly important for the long, demanding saturation dives that will be undertaken in the near future. The additional toilet could be located in A chamber where piping for a drain from that chamber already exists. (Priority 1)
- (42) Because of the importance of all available space in a hyperbaric chamber, it is recommended that the BIBS humidification system be moved to the outside of the chamber if possible. (Priority 4)
- (43) The current grate on the deck in the shower (Fig. 26) should be replaced with a finer mesh design which will be more comfortable to the feet and less likely to produce toe and foot injuries. (Priority 3)
- (44) It is recommended that a padded cover be added to the deck penetrator (Fig. 27) in C chamber to prevent foot contact injuries during diving operations. (Priority 3)
- (45) Provisions should be made for a tool box and first aid kit for the chamber interior and a location for their storage should be



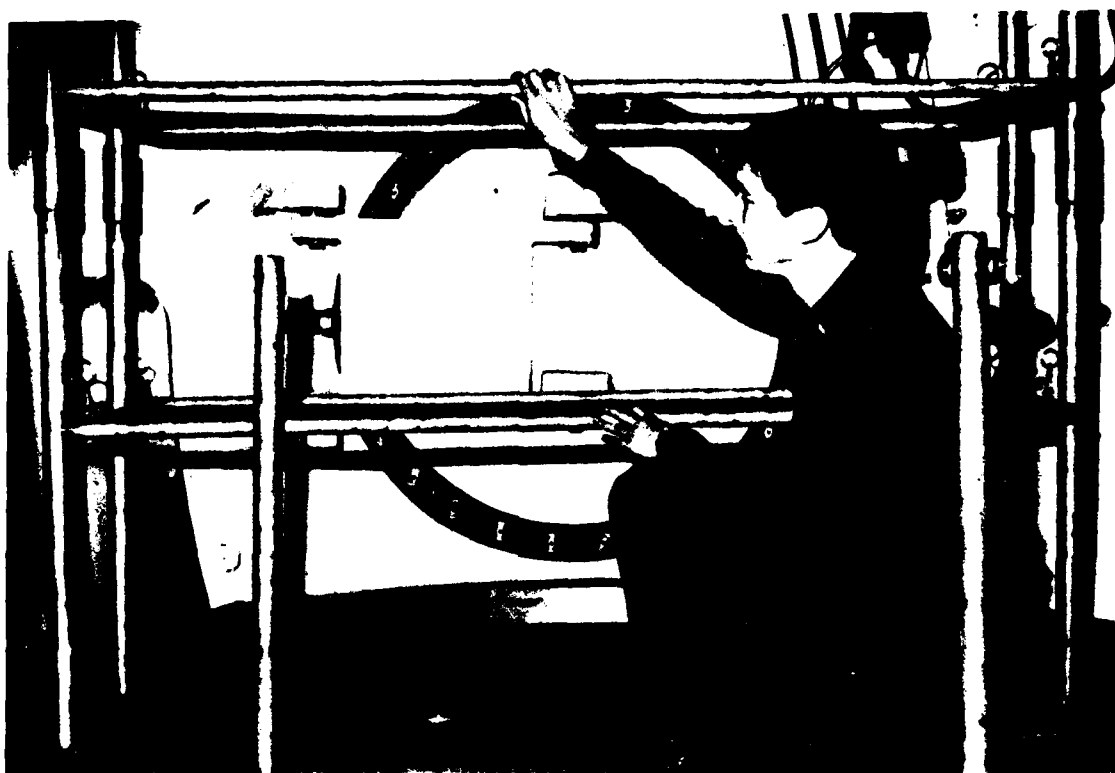


Fig. 23. Removable brackets for bunks in C chamber.

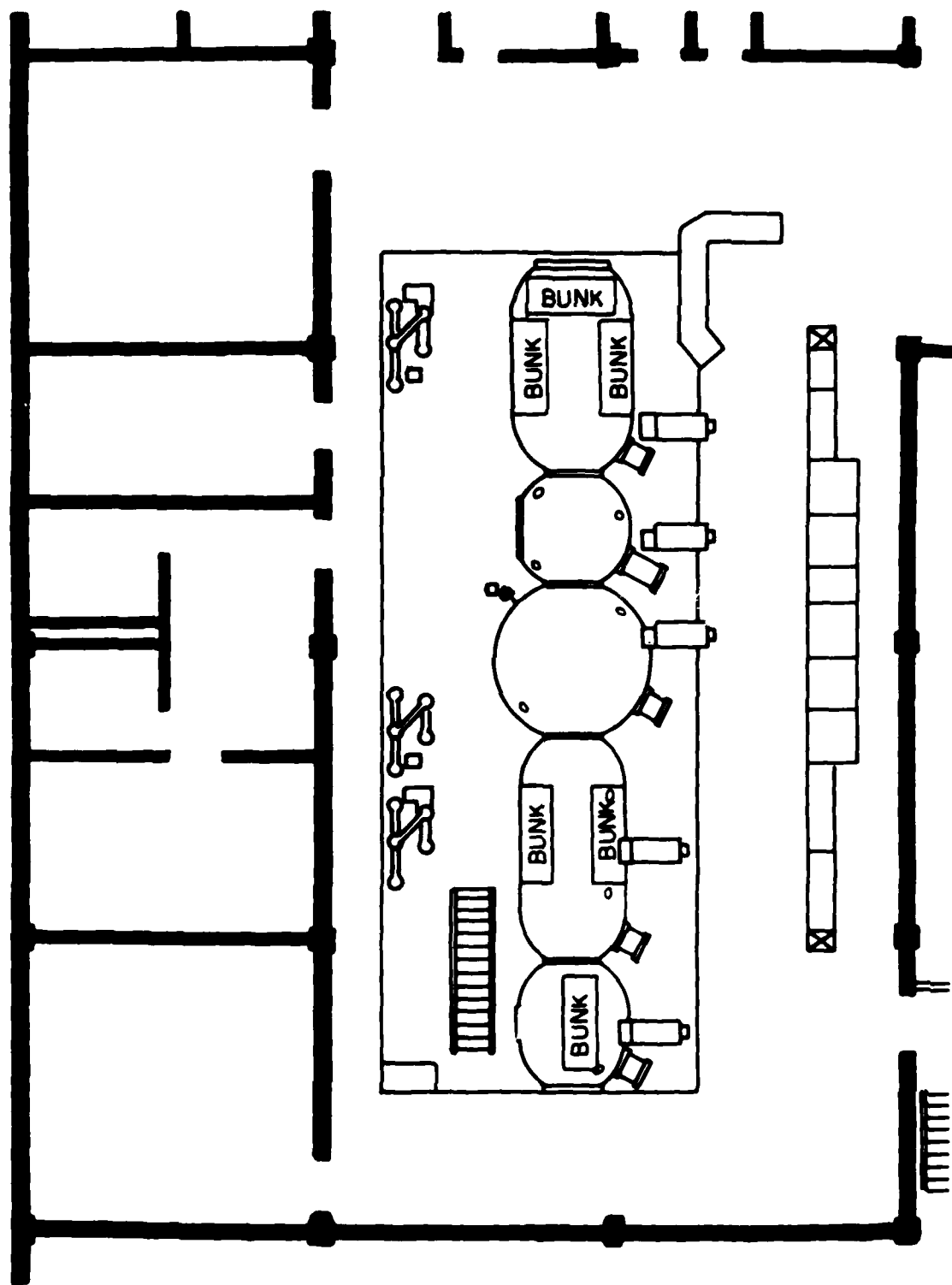


Fig. 24. Recommended bunk arrangement when entire complex is at depth.

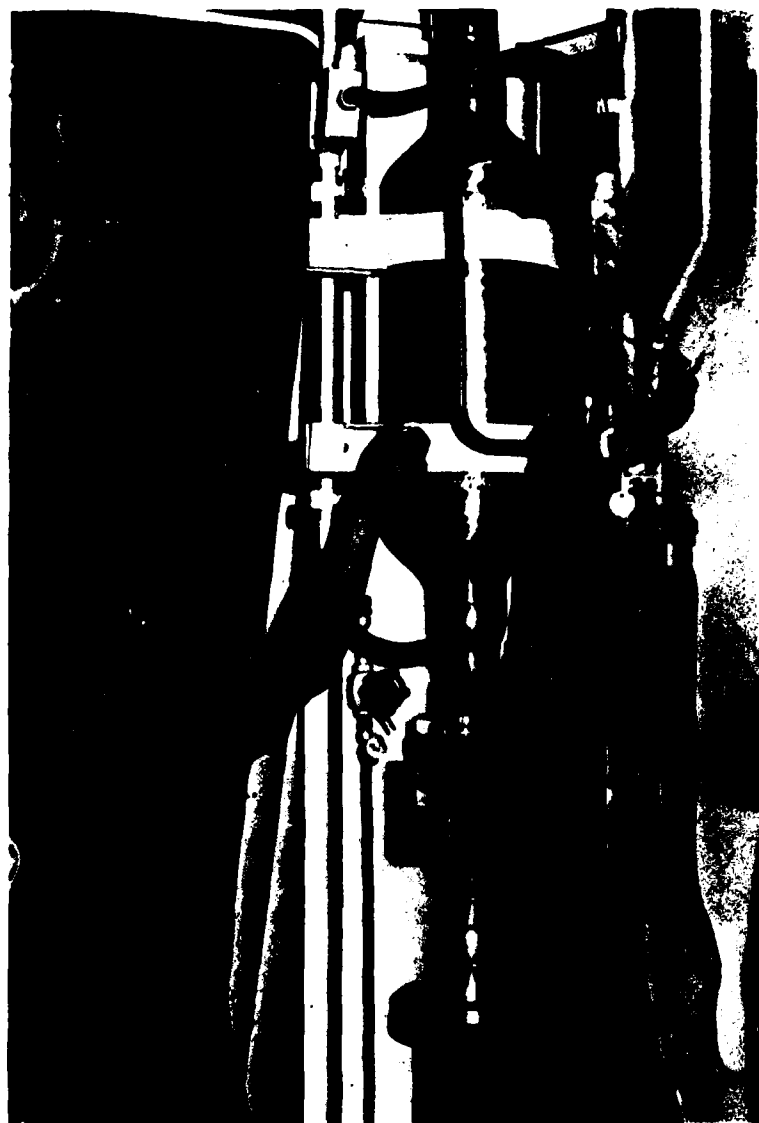


Fig. 25. Current HRF sanitary holding tank.



Fig. 26. Present design of shower deck plate. Note large gaps in mesh which could lead to toe and foot injuries.



Fig. 27. Unpadded deck penetrator in C chamber which could produce toe and foot injuries.

determined. The B chamber, which will probably be a transit chamber primarily, might be an appropriate location for such storage. (Priority 1)

(46) A flexible hose attachment for the shower head in C chamber would allow the rinsing of diving suits and other equipment during saturation dives. Use of the hoses in the other chambers for such purposes is generally undesirable since they would tap the FES holding tanks and would, no doubt, increase humidity and produce water splatter problems in the living chambers. (Priority 3)

(47) Storage space should be provided for toilet articles and limited personal belongings. Several possible locations include below bunk shelves or boxes and above hatchway shelving. (Priority 2)

(48) It is recommended that the feasibility of installing a porous privacy curtain around the toilet be investigated. (Priority 3)

(49) A removable upper ladder assembly extending up into C chamber should be added to the existing wetpot ladder for ease of diver deployment and recovery. (Priority 1)

(50) To enhance chamber habitability, it is recommended that the interior walls be painted in light pastels (e.g. blues, tans, yellows, etc.). For suggested paint schemes refer to McCann (1). (Priority 4)

(51) An examination of the video coverage in each chamber showed that an adequate diver monitoring capability exists. The current camera placements provide good interior chamber views.

(52) Figure 28 shows the present design of the gas analysis patch panel. As can be seen, no attempt was made to group components by function or to color-code them in a manner to clarify their purpose to an

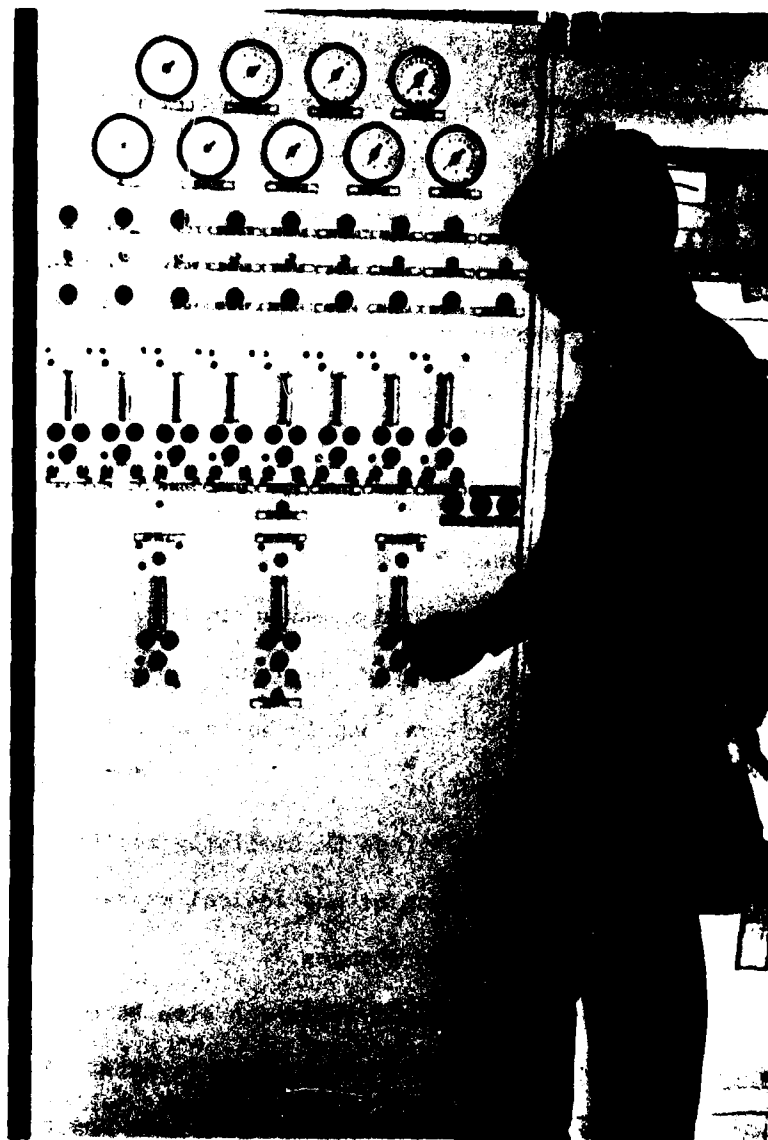


Fig. 28. Present design of the gas analysis patch panel.

operator. Figure 29 shows the recommended changes. This layout does not require the movement or alteration of any of the hardware (although several more efficient designs could be devised). It simply employs functional grouping and color coding. This design should improve operator recognition and readability while reducing errors. (Priority 2)

- (53) Figure 30 shows the present gas analysis instrumentation panel. The recommended changes are similar to those above (see Fig. 31). (Priority 2)
- (54) Figure 8 showed the face of a local control panel. Greater clarity of function can be obtained by concise gas paths and simple noncoded labeling. The recommended scheme is shown in Fig. 32. (Priority 2)
- (55) It is recommended that the sanitary dump and potable water control buttons on the side of the local panels be sequenced from left to right in the proper order of use. (Priority 2)
- (56) The operating panels (Fig. 33) can be similarly modified to improve their organization in a meaningful and logical manner. Figure 34 shows a layout for recommended changes. (Priority 2)
- (57) The chamber exteriors and medical locks can also be color-coded to coincide with the suggested control panel layouts. An 18 in. wide solid color band running up the side and over the top of the chamber is the recommended technique. (Priority 3)
- (58) In order that the status of the chamber closure valves can be easily determined, it is recommended that a yellow status light be installed next to the chamber closure button on the control panels. Such a light would be illuminated when the chamber closure valves have been activated. (Priority 2)



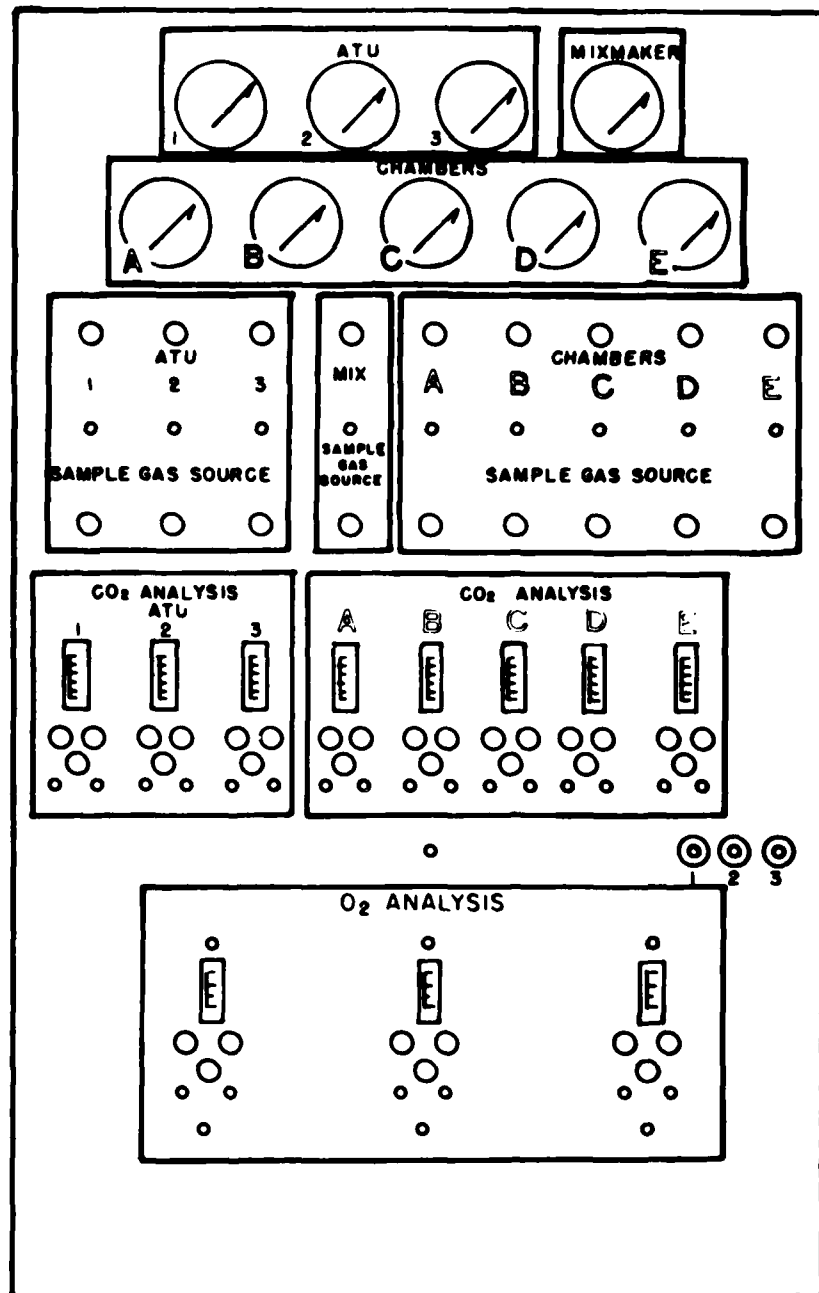


Fig. 29. A proposed layout for the gas analysis patch panel. Gauges and valves are labeled in a simple, easily understandable manner and components of similar function are grouped together graphically and color-coded.

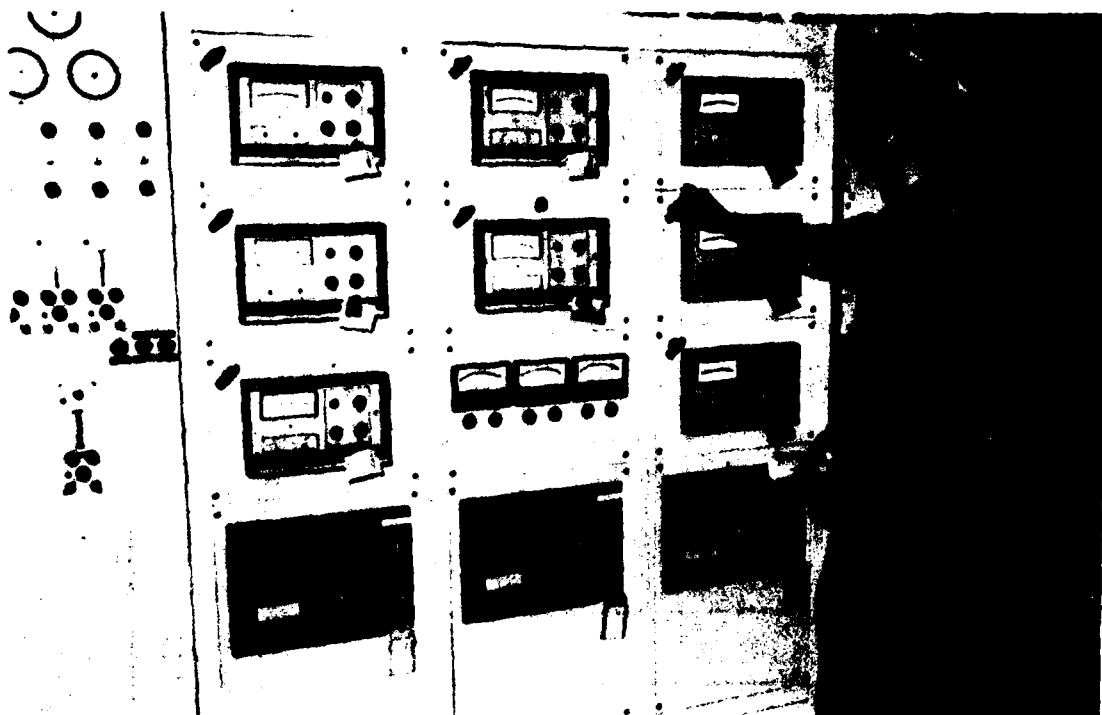


Fig. 30. Present design of gas analysis instrumentation panel.

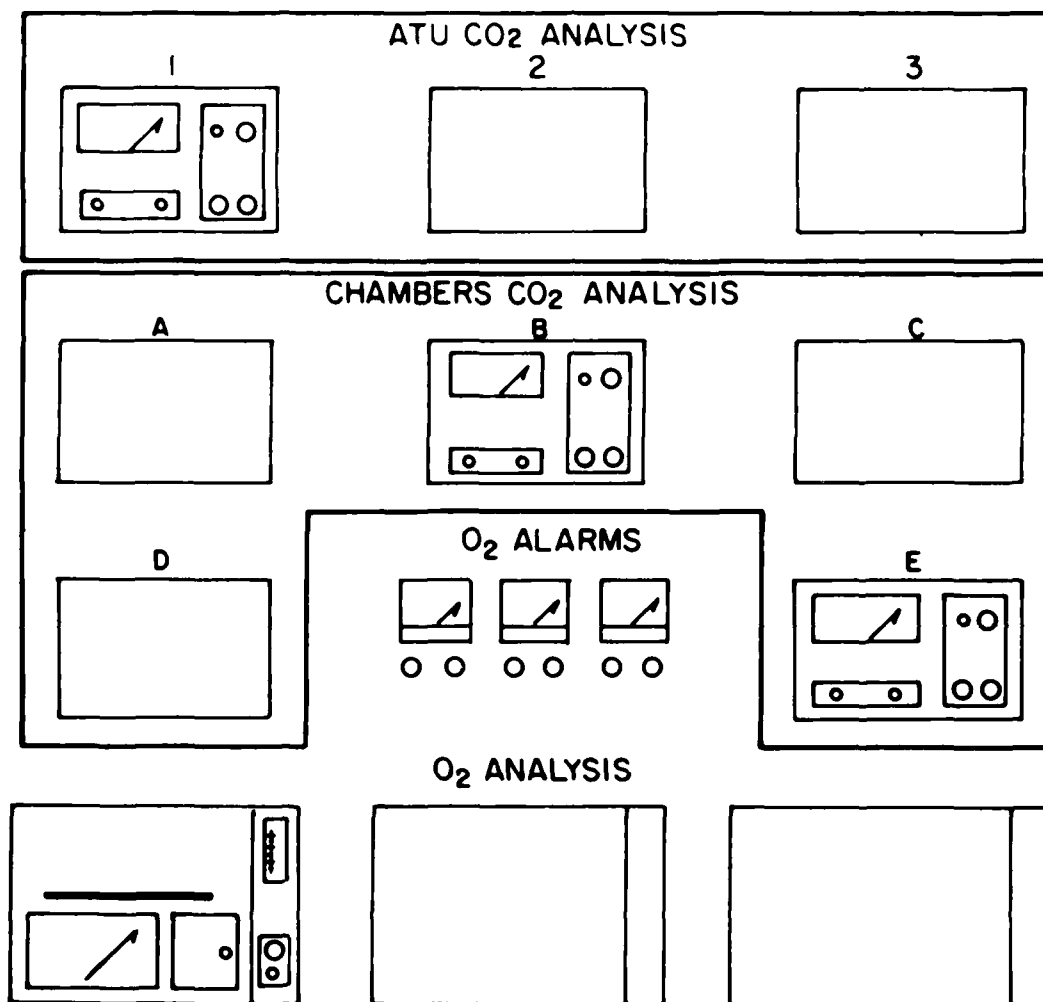


Fig. 31. A proposed layout for the gas analysis instrumentation panel. Again, functional grouping, color-coding, and large simplistic labeling have been employed to improve readability and decrease recognition time.

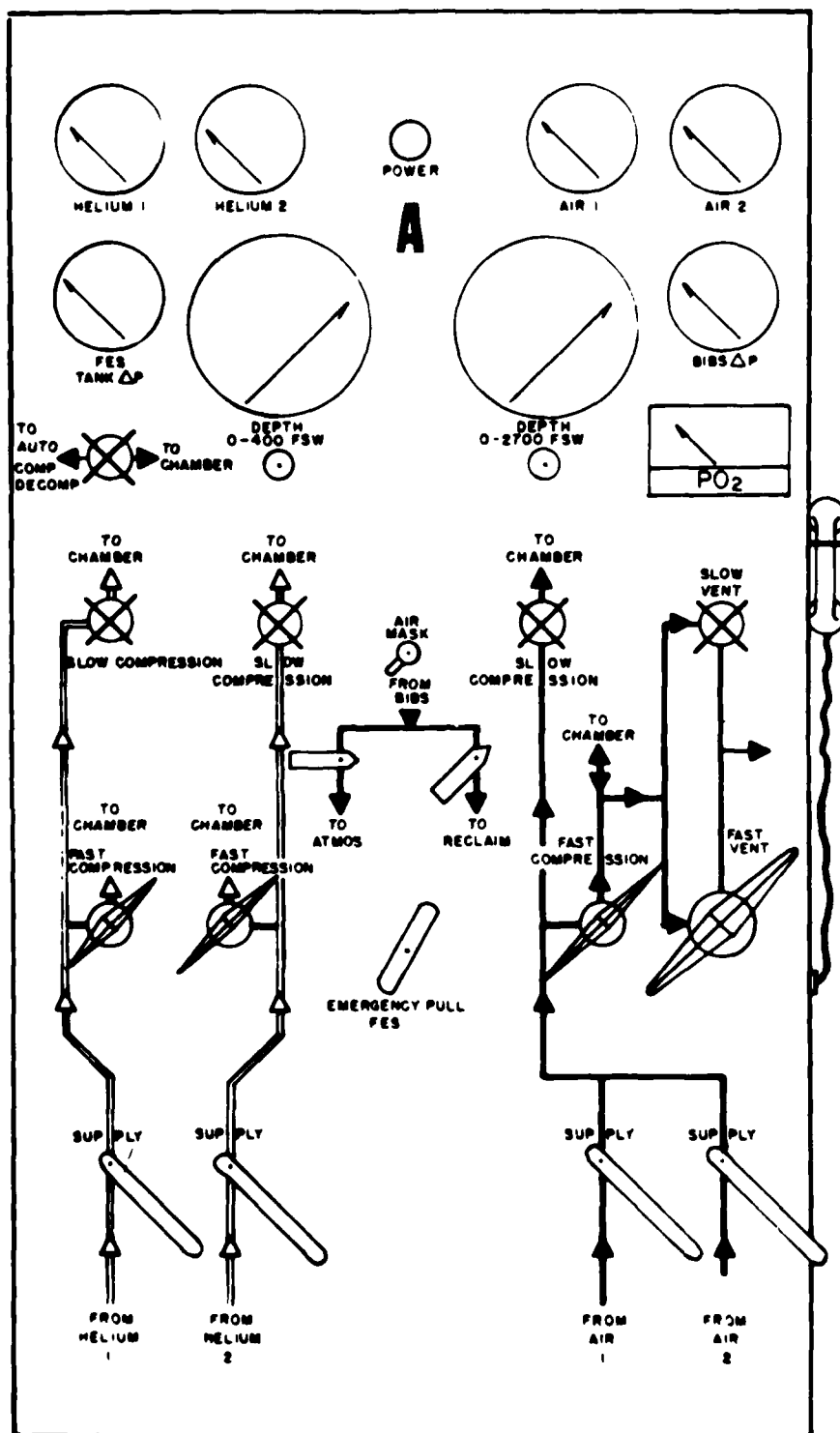


Fig. 32. A proposed layout for the local control panel. Gas paths would be appropriately color-coded.

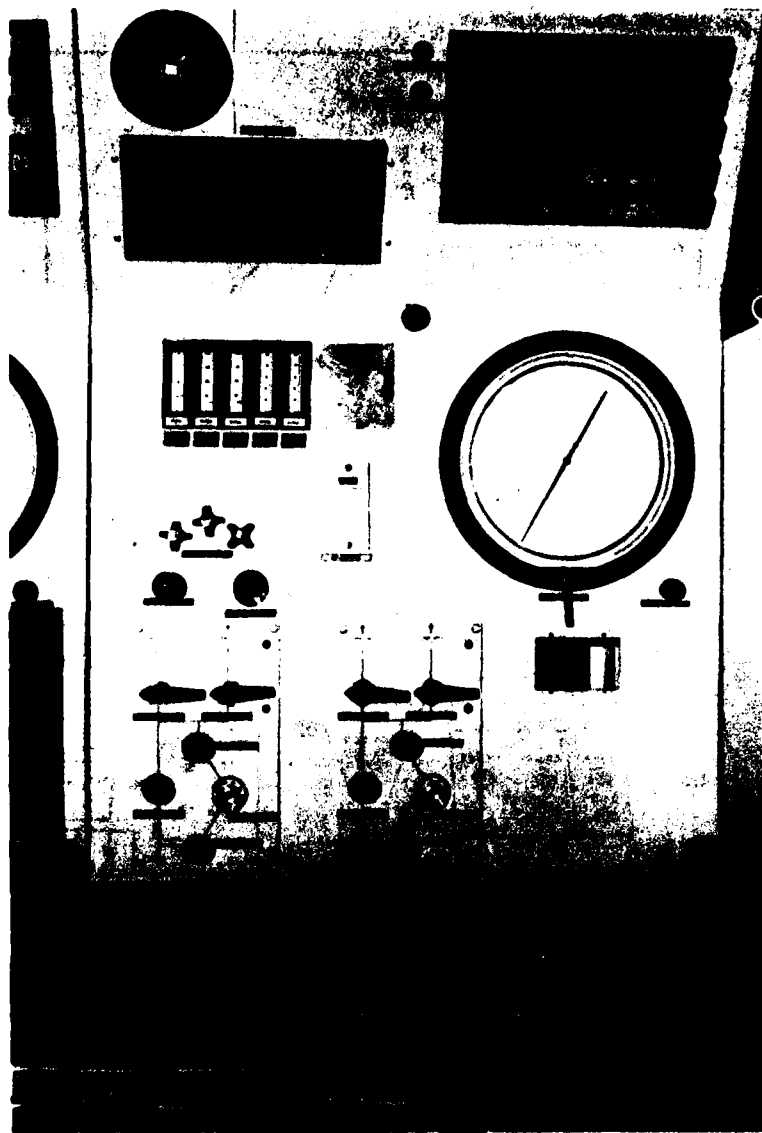


Fig. 33. Current configuration of a master console operating panel.

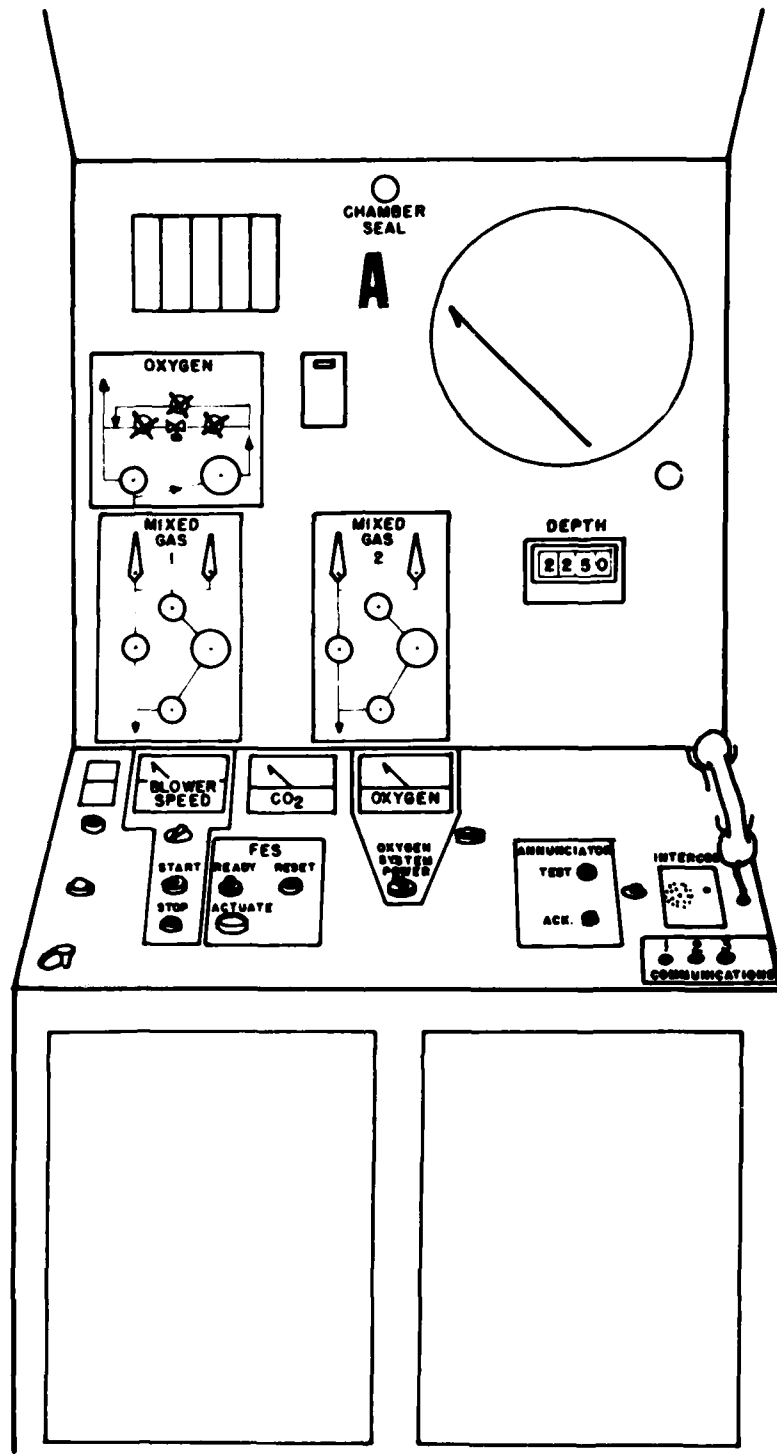


Fig. 34. A proposed layout for the operating panels.

- (59) It is recommended that activation of the FES automatically turn off the life support blowers to prevent various loop alignments from spreading smoke and fumes throughout the chambers. (Priority 1)
- (60) It is recommended that the pressure gauges (shown in Fig. 35) be repositioned to a more readable height (60-70 in. above the floor, ideally). (Priority 3)
- (61) If the chamber clothing of the divers is to be cleaned at HMPC during saturation dives, then a laundry capability and location must be provided. (Priority 4)
- (62) Because the NNMC base has unguarded entrances, it is recommended that video surveillance be maintained on the bottlefield at all times during saturation dives. Such monitoring could be accomplished automatically or displayed at the central monitoring console, or both. (Priority 1)

#### Environmental Parameters

- (1) As previously mentioned, recorded noise levels in several places within the HRF approach the upper limit of the OSHA standards for an 8 h exposure. Figure 36 indicates the 13 locations where sound levels were periodically recorded. The circled numbers rank the locations from the lowest noise level [1] to the highest [13]. The lower noise levels which occur in the vicinity of the operating panels are still high enough to fatigue operators exposed to them for lengthy periods of time and to reduce communication efficiency between members of the diving watch as well as between the diving watch and divers within the chamber. The major contributors to the noise levels in the immediate chamber

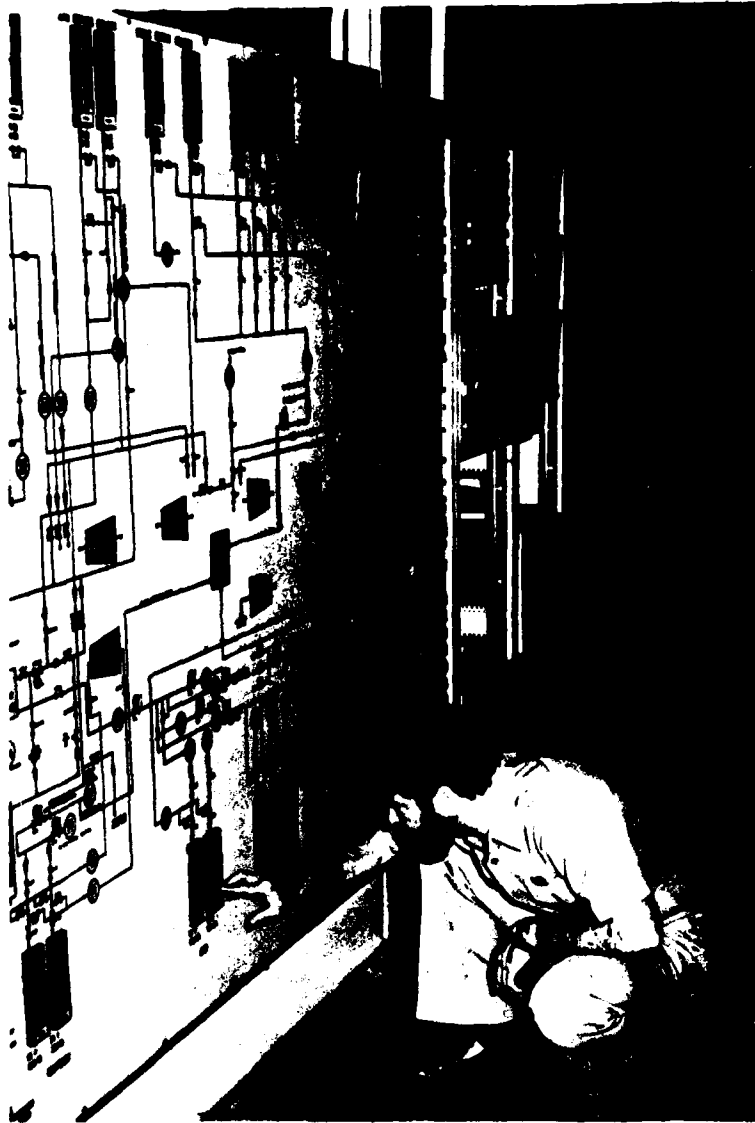


Fig. 35. Present position of pressure gauges on gas status panel.



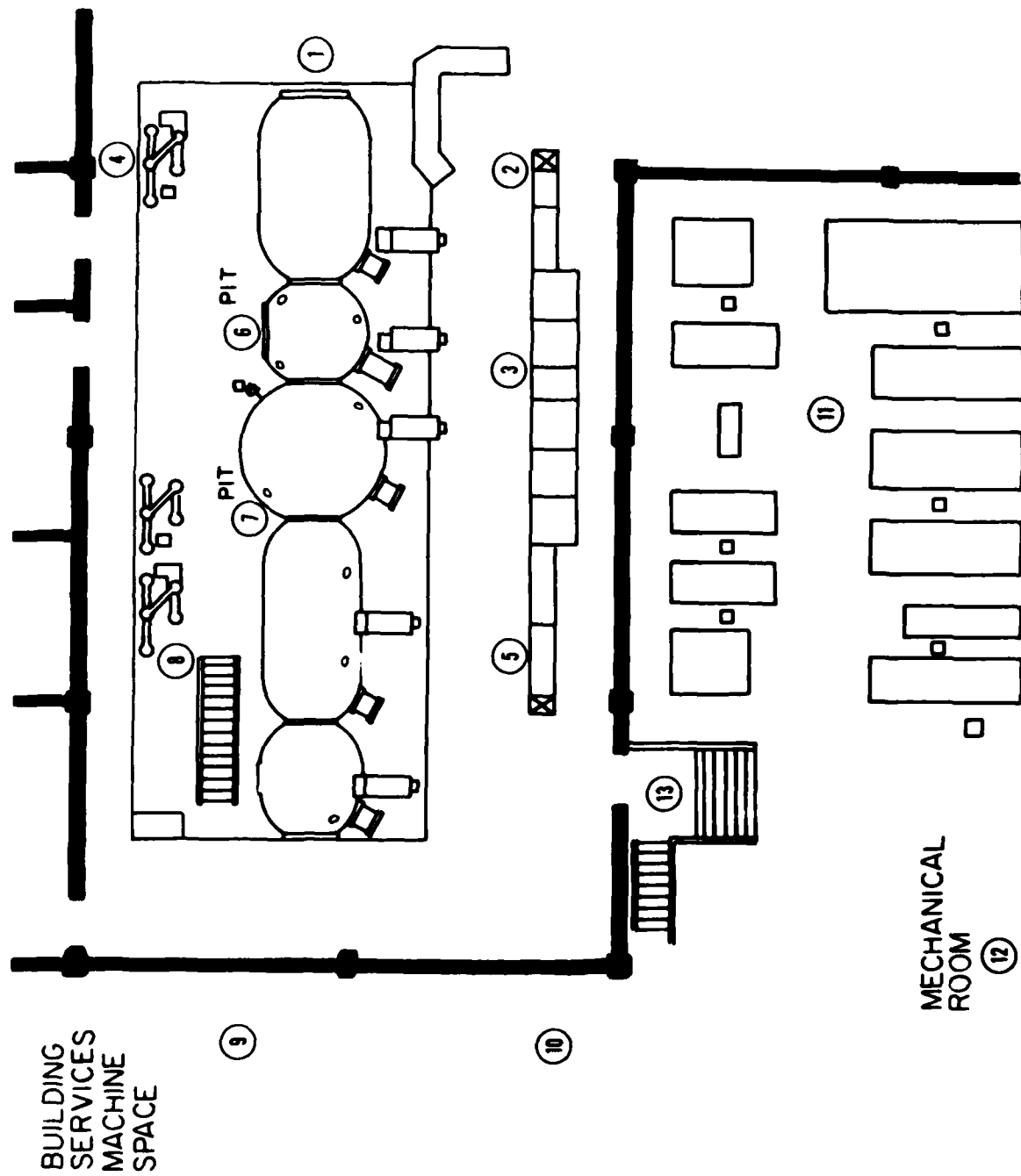


Fig. 36. The 13 locations in which noise levels were measured. The higher the number, the higher the recorded noise level.

area are the building air conditioning system and the motors, which drive the life-support blowers for the chambers. Octave band analysis of the noise spectrum associated with the building air conditioning system and 1, 2, or 3 ACS blowers is shown for three locations in the immediate chamber area (Fig. 37, 38, and 39). As can be seen, the peak noise levels produced by these machines, fall in the same frequency range as the peak levels in male speech at conversational intensities. Thus, ear protectors to attenuate the peak noise frequencies will also reduce an individual's ability to understand human speech, since they share the same peak frequencies. Consequently, personnel-worn ear protectors, while reducing the danger of hearing damage due to the high noise intensity, will reduce communication capabilities markedly. Anything less than optimal communication conditions in the operator control areas of the hyperbaric saturation diving system is unacceptable. It is felt that the primary noise sources can and must be effectively attenuated at their sources. The highest noise levels (85-98 dB) were observed, not surprisingly, in the compressor room adjacent to the chamber area. A sound-protected office is already planned for personnel working in this area, but personnel should wear ear plugs (or similar equipment) when working around the compressors and machinery.

(Priority 1)

- (2) For most display, control panel, and work place applications, luminance (or brightness) is the important measurement regarding the visibility of the information presented. Measurements of luminance in foot-lamberts (ft-L) were recorded for a variety of locations in and around the chamber complex. These locations included the

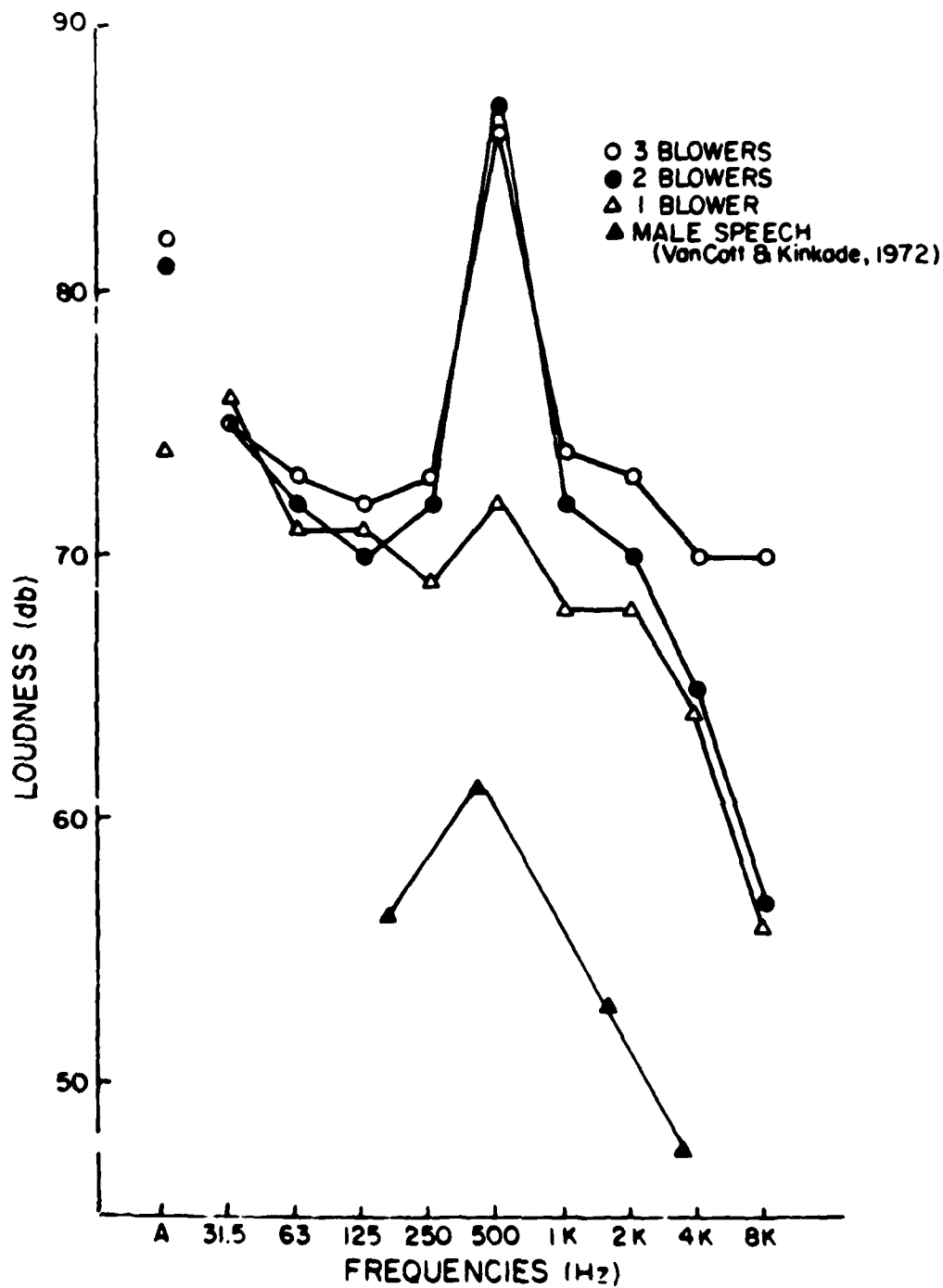


Fig. 27. Octave band analysis of the noise spectrum associated with the building air conditioning system and 1, 2, or 3 ACS blowers recorded at master console. Peak levels in male speech at conversational intensities are also provided.

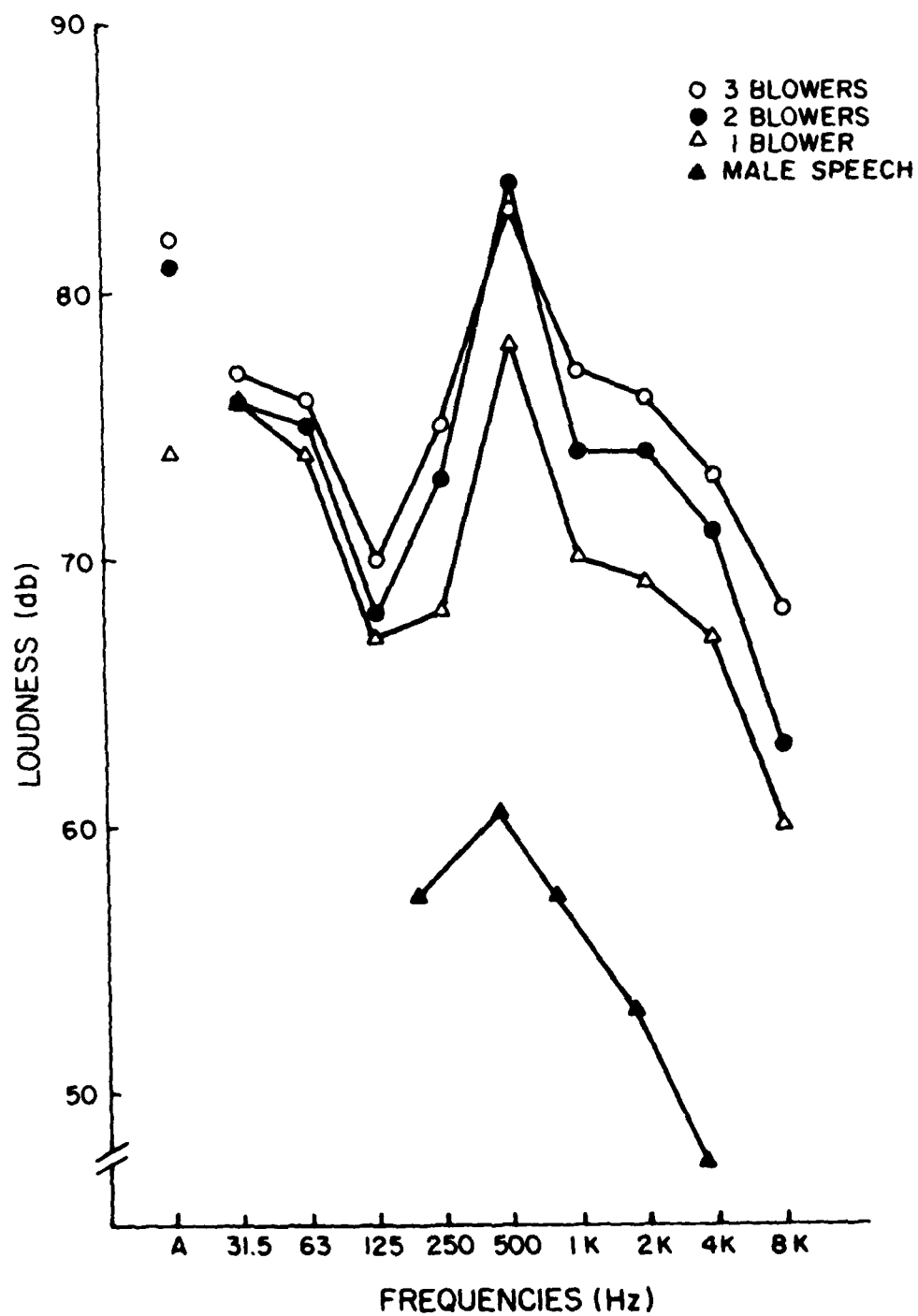


Fig. 38. Octave band analysis of the noise at the A chamber ACS loop.

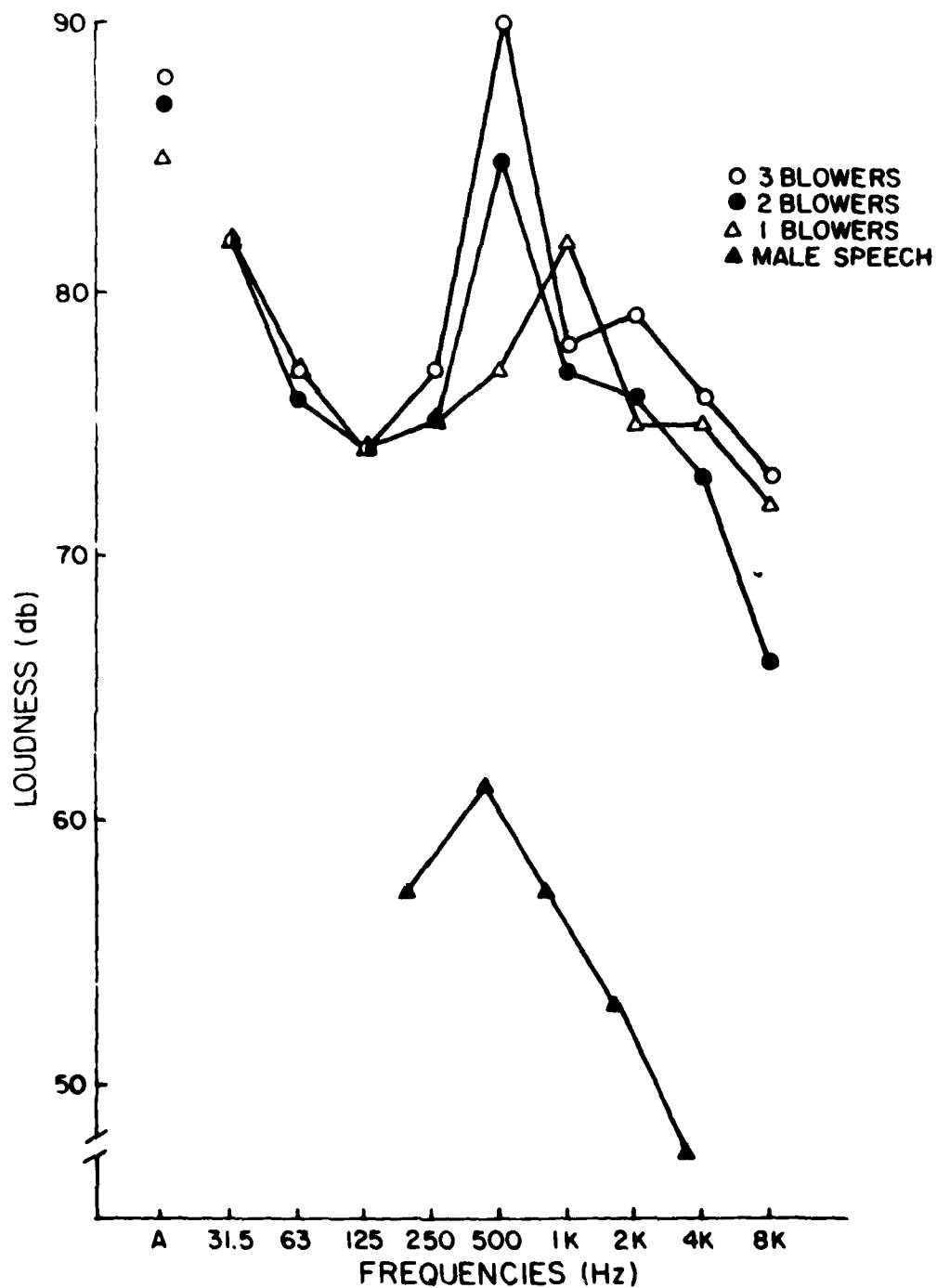


Fig. 39. Octave band analysis of the noise at the D chamber ACS loop.

interior of D chamber, each local control panel, the master control console, gas analysis panels, life support loop gauges, components within the compressor room, and the bottlefield alleyway gauges. The recommended luminance levels for indicator readings, legends on consoles, and chart readings, generally fall between 1-20 ft-L (4). With the exception of two bank pressure gauges in the center of the bottlefield alleyway, all consoles and locations fall within these prescribed limits. Simply turning on the alleyway lighting (normally used at night) during the day, should raise the luminance levels within acceptable limits. (Priority 2)

Nighttime light levels in the bottlefield alleyway, and at both the oxygen reducing station and truck charging station were also within limits. In order for the D chamber interior to meet recommended levels, it was necessary to have the Canty<sub>TR</sub> light powerstat controllers set at 70.

#### Personnel Requirements

The present Watchstanding Qualification Program (NMRI INST 9940.3) describes watchstanding requirements for eight positions (excluding inside chamber diver/tender). These are diving watch officer, diving watch supervisor, medical watch officer, life support systems operator, gas king, atmosphere monitoring operator, operating/local panel operator, and console communications operator/log keeper.

The following modifications are suggested:

- (1) The console communications operator/log keeper should be divided into two separate watch positions during saturation dives.

Communications and video systems as complex as those employed in

the HRF require, if not continuous, at least very frequent adjustment. In addition, this individual, usually an electrical specialist, is responsible for any related electrical malfunctions such as lighting, annunciator alarm difficulties, etc. The log keeper, on the other hand, is responsible for not only the frequent routine log entries characteristic of chamber dives but the entry of most malfunctions encountered as they occur. In addition, he usually responds to any incoming telephone calls so that other watch stations are not unduly interrupted. (Priority 2)

- (2) The use of two individuals should be considered for the life support systems watch. In addition to the usual rounds that must be made, the watch is responsible for the changing of CO<sub>2</sub> cannisters as needed and minor maintenance on the system during diving operations. An additional individual also provides the diving watch officer and diving watch supervisor with a certain flexibility, should unforeseen circumstances within the HRF arise. (Priority 2)

Of course, in addition to the above mentioned watch stations, a cook will be required to provide meals to the divers in the chamber on a reasonably flexible basis (0530-1900 h). An instrumentation specialist will also be required during the day watch (0730-1600) on saturation dives to support biomedical and diving equipment requirements encountered during the medical experiments at depth.

Until now, a location for the biomedical research equipment and research personnel during diving operations was not allocated. The recommended site for such a capability was shown previously in Fig. 7. (Priority 1)

This location was chosen for several reasons. First, it is next to the elevator leading to the office and research areas on the floor above. Escorted visitors (visiting scientists, dignitaries, etc.) will not have to traverse the operational diving areas of the facility. Second, it is in close proximity to the chambers themselves for easy access to chamber penetrators. And third, entrance to this area is in plain view of the projected site of the central monitoring console where the diving watch officer and diving watch supervisor will be located. This should facilitate coordination and cooperation during diving experiments. Figure 7 also showed the location of a fold-a-way visitor retaining barrier, so that the chamber and control consoles can be viewed but not interfered with, during diving operations. (Priority 3)

The current galley size is inadequate for food preparation and storage during long saturation dives. Several alternative locations have been identified in the immediate chamber area. The room immediately to the left of the medical research area is one possibility. It is close to the chambers and central monitoring console but would require plumbing for the addition of a sink. In addition, a room for food preparation has been provided off the animal hyperbaric chamber area, immediately adjacent to the human hyperbaric chambers. This room is of adequate size and already contains a large stainless steel sink.

Ten watchstanders are required to run the system during a saturation dive, if the cook, instrumentation specialist, divers within the chamber, and biomedical personnel are not counted. If three 8 h watch sections are to be utilized, then a minimum of 30



individuals are required. Add to this, the cook, the instrument specialist, six subject divers, and the number grows to 38. This number currently exceeds the onboard roster of potentially qualified personnel. Substantial increases in HMPC diving personnel will be required or a drastic alteration in the watch standing procedures will be necessary if the HRF is to be utilized to its fullest degree.

#### Emergency Systems/Alarms

The effectiveness of emergency systems, procedures, and alarms in a man-machine system is in large measure dependent on the response of the human operator. The adequacy of his response is a function of his recognition that an emergency exists via some "alarm," his previous training, the physical actions required of him, and the adequacy of the equipment's response to his manipulation. Taken as a whole, this sequence will determine the effectiveness with which the emergency is dealt with. Any component of this sequence can have substantial effects on overall system effectiveness.

The HRF's present annunciator panels (shown in the upper portion of Fig. 33) provide equipment status as well as emergency information via both visual and auditory alarms. When certain conditions are "sensed," a flashing component of the annunciator panel is activated which displays the appropriate information. Simultaneously, a loud intermittent auditory beep is sounded. When the operator acknowledges the alarm with a pushbutton, the auditory alarm stops and the flashing visual display becomes continuously lit until the alarm condition is rectified. This particular approach to alarm recognition is a good one, provided frequent inconsequential information is not being displayed in this manner. If inconsequential information is presented, an operator's response to the alarms is gradually slowed as alarm adaptation occurs. Without requiring the need of quick response, the

alarm system gradually loses its attention getting value and the possibility of a slowed inadequate response to a true emergency alarm is increased.

It is recommended that an emergency annunciator panel be installed in the central monitoring console so that the dive supervisor and dive officer have easy visual access to it. (Priority 2)

#### DISCUSSION

This evaluation has sought to identify human engineering deficiencies in the HRF diving complex. It is important to note that the study was conducted prior to the operational readiness of the system and before its official turnover by the contractor to the Navy. Once the facility is fully operational, additional problem areas will undoubtedly become evident.

Table 1 shows the distribution of the recommendations made across the four priority levels. Recall that in order for a recommendation to be assigned to the priority one category it had to involve, in the opinions of the authors, a critical potential safety hazard or pose a condition which greatly limited the practical readiness of the system for operational use. The assignment of priorities was somewhat arbitrary, with many discrepancies presently assigned to priority two being reasonably eligible for the priority one category. Although recommendations regarding functional grouping, color-coding, and placement of controls are listed as less than priority one, one should be cognizant of the potentially serious consequences of grabbing the incorrect valve or failing to reach a control in an emergency situation. The probability of the occurrence of emergency conditions should be very low, however, failure to respond correctly should an emergency arise tends to have substantially more serious consequences than failure to respond in a nonemergency. Although a number of the required recommendations can be accomplished relatively quickly and inexpensively, the bulk of them will involve costly

TABLE 1. Distribution of recommendations across the four priority levels.

	PRIORITY LEVEL				Total
	1	2	3	4	
Number of Recommendations	13	27	17	10	67

delays and prove to be extraordinarily expensive. These expenditures of time and money could have been avoided to a large degree by incorporating human factors input during the soft design phases of the HRF. The importance of involving human engineers in the initial design stages of complex man-machine systems can not be over-emphasized.

A frequent obstacle to the reconfiguration of facilities under construction or already built is the lack of documentation of changes in the system. The rationale for changes, when and by whom initiated, should be meticulously recorded so that replacement personnel can be properly appraised of the system's evolution. This documentation is essential in institutions where there is a high turnover of personnel (e.g. military) and construction takes place over many years. In the course of this study, the authors frequently found themselves asking why a particular design was used or why a change was undertaken, only to be met with a lack of information. As the HRF has been planned for a decade and under construction for five years, it is recommended that written records be kept of design changes and particularly the rationale behind these changes.

Phase II of this evaluation should begin when the HRF has become operational. It will be then that the more subtle procedural, information processing, and task analytic characteristics can be examined more fully. Such an evaluation can be coupled to the actual diving operations of the complex with little interference to ongoing medical and physiological projects.

Several relevant areas suggest themselves for investigation. An analysis of watchstanding activity could provide significant information on which to base the efficient use and placement of watchstanders. This analysis could impact upon the number of watchstanders needed for particular dives, the temporal patterning of duties and schedules, and the elimination of redundancy among stations. This study would involve a task analysis, including number

of tasks, steps involved in tasks, time required for task completion, and temporal distribution through the watch. Due to projected difficulties in obtaining full manning, this analysis may prove valuable. Additional human engineering aspects appropriate for investigation include an evaluation of the communications network when the complex is at depth (including the effectiveness of the helium speech unscramblers), the monitoring of noise levels inside the chamber at depth, the habitability of the living spaces in relation to gas flow and temperature when at depth, and the accuracy and variability of operator performance in reading gauges from gas analysis panels, control consoles, and compressors.

The human engineering deficiencies noted in this report, along with the work of McCann (1), and Banks, et al. (9) should prove useful in assisting designers and operators of other hyperbaric complexes in the safe, efficient design and operation of their systems. Numerous technical references are available (e.g. 4, 7, 8) to guide the engineers in their role, however, until recently there were few nontechnical publications available to guide the hyperbaric user through a simple human engineering evaluation of their system.

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